POWER CONTROL DELAY IN WCDMA MOBILE RADIO NETWORKS

Vladimír Wieser[a), Vladimír Pšenák [b)

[a)]*Katedra telekomunikácií, Elektrotechnická fakulta ŽU v Žiline*
Veľký diel, 010 26 Žilina, tel.: +421 41 513 2260, mail: wieser@fel.utc.sk
[b)]*Siemens Program and System Engineering s.r.o,*
Bytčická 2, 010 01 Žilina, tel.: +421 907 898 215, mail: vladimir.psenak@siemens.com

Summary This article presents the basic theory of power control and deals with the mutual interference among mobile subscribers (basic stations) in uplink (downlink). Considering the SIR requirements, each transmitter in the WCDMA network have to use minimum output power, which is necessary to span channel fading. Accurate transmitter power level can be achieved by using optional power control loops, which send appropriate Transmitter Power Control (TPC) commands through dedicated feedback channel. Effect of power control commands delay in the WCDMA mobile radio network are presented by uplink simulations results. Presented power control loop is based on the standardized algorithm. The investigation of the influence of TPC commands delay in the case of high speed mobile subscriber helps in designing the optional link adaptation algorithm.

1. INTRODUCTION

Fast transmitter power control is essential in WCDMA mobile radio networks, in particular on the uplink (without it, a single overpowered mobile station MS could block the whole cell [8]). Power control algorithms play an important role for efficient resource utilization. Generally, it can be written that power control for each (uplink or downlink) connection is implemented as cascade control with an inner loop (to compensate fast variations) and an outer loop (focused on long-term statistic). These loops are interrelated via complex connections, which affect important issues, such as capacity, load and stability [1]. Inner loop includes closed power loop and open power loop, which is used for the initial output power level of transmitter according to measurements of pilot signal.

2. BASIC THEORY

The power of each transmitter is limited by resource usage of the link, but the links typically occupies the same frequency spectrum for efficiency reason. Resource management is needed to utilize the radio resource efficiently, because links mutually interfere with each other. The receiver can recover desired signals according to the links' assigned codes. The perceived quality is related to the Signal-to-Interference ratio (SIR):

$$\gamma(t) = \frac{p(t)g(t)}{i(t)} \tag{1}$$

where p(t) is transmitter power used to transmit data scrambled by user-specific code (small caps indicated linear scale), g(t) is the channel power gain (<1) and $\mathrm{G}(\mathrm{t}) = 10\log_{10}(\mathrm{g}(\mathrm{t}))$ [9] (big letters indicate logarithmic scale), i(t) is interfering power from other connections. For error free transmission, the achievable data rate R(t) is given by [12]:

$$R(t) = W \log_2[1 + \mathrm{SIR}(t)] \quad [\mathrm{Bit/s}] \tag{2}$$

where W is bandwidth in Hertz. The power control objective is to maintain constant SIR and thereby constant data rate or to use constant power and adapt the data rate (adaptive coding) or to transmit only in the case of channel good conditions or to use combination of these objectives.

In the simple case, when only two users are in the cell, base station broadcasts the common information with the power $p_{BS\_C}(t)$ and dedicated information is transmitted using the power $p_{BS\_D}(t)$:

$$p_{BS\_D}(t) = p_{BS\_D1}(t) + p_{BS\_D2}(t) \tag{3}$$

where $p_{BS\_D1}(t)$ is power used to transmit dedicated information to MS_1 and $p_{BS\_D2}(t)$ is power used to transmit dedicated information to MS_2.

Orthogonal channelization codes reduce the mutual interference between signals [13], but due to the channel effects and non-ideal receivers, this orthogonality is not fully maintained, and the fraction α_i $(0 \le \alpha \le 1)$ of it still remains. Therefore SIR at MS_1 is given by:

$$\gamma_{MS1d}(t) = \frac{p_1(t)g_1(t)}{\alpha_1[p_{BS\_C}(t) + p_2(t)]g_1(t) + \nu_{MS1}(t)} \tag{4}$$

where $\nu_{MS1}(t)$ is thermal noise at MS_1.

In the uplink, both signals from users pass through independent channels, therefore it is better to use codes with good correlation properties [13]. The SIR at BS is given by:

$$\gamma_{BSu}(t) = \frac{p_1(t)g_1(t)}{p_2(t)g_2(t) + \nu_{BS}(t)} \quad (5)$$

where $\nu_{BS}(t)$ is the thermal noise at BS. In the case when MS_1 is at the cell edge, it suffers a higher path loss than MS_2, which is e.g. near the BS. Power control has to set the appropriate output power levels of both MSs. This means, that BS receives the signal from both MSs at the same level (so called near-far problem) [8].

Power control is used to maintain required SIR, which is regularly assigned to each connection-oriented service. Required SIR, $\gamma_i^t(t)$ reflects specified data rate and error rate of the connection. Power control is based on feedback of the error $e_i(t)$:

$$e_i(t) = \gamma_i^t(t) - \gamma_{MSi}(t) \quad (6)$$

where $\gamma_i^t(t)$ is required SIR and $\gamma_{MSi}(t)$ is actual achieved SIR for MS_i. This feedback information has to be sent to the transmitter by using valuable bandwidth, therefore it should be kept at minimum. If link has integrated power control, output power level of transmitter is defined as follow:

$$p_{MSi}(t+1) = p_{MSi}(t) + \beta f[e_i(t)] \quad (7)$$

where $f[e_i(t)]$ represents function, which is responsible for feedback communication. Expression $\beta f[e_i(t)]$ is called power step: $p_{TPCi}(t)$.

For example, if power control uses single-bit quantization, then power step:

$$p_{TPCi}(t) = \begin{cases} +\Delta p \\ -\Delta p \end{cases} \quad (8)$$

where Δp [dB] is predefined fixed power control step. There is also another alternative algorithm, described in [2]. This makes it possible to emulate slower update rates, or to turn off uplink power control by transmitting an alternating series of TPC commands. In a 5-slot cycle $(j = 1,...,5)$, the power step $p_{TPCi}(t)$ is computed according to:

$$p_{TPCi} = \begin{cases} +\Delta p & (j=5) \& \left(\sum_{j=1}^{5} S_i(j) = 5\right) \\ -\Delta p & (j=5) \& \left(\sum_{j=1}^{5} S_i(j) = -5\right) \\ otherwise & \end{cases} \quad (9)$$

3. STANDARDIZED ALGORITHM

On the fig. 1 the block diagram of general SIR-based power control algorithm is created. Several algorithms are standardized by 3GPP [3]. The model presented in this article is based on the 3GPP UMTS standard.

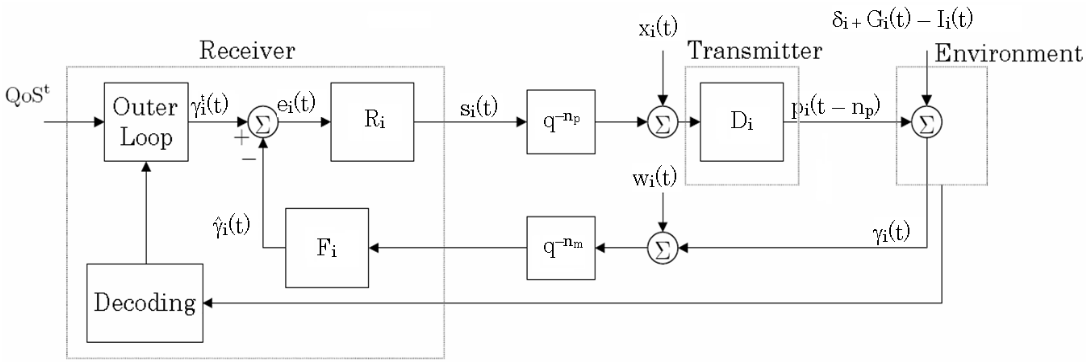

Fig. 1 Basic SIR-based power control algorithm

The receiver computes the error $e_i(t)$ as the difference between required SIR $\gamma_i^t(t)$ and measured SIR $\hat{\gamma}_i(t)$ (block F_i also contains an appropriate filter; measurement noise $w_i(t)$ and interference). The error is coded into the power control commands $s_i(t)$ by the block R_i, affected by command errors $x_i(t)$ on the feedback channel and decoded on the transmitter side by the block D_i (closed power loop). The accuracy of the control loop depends on the power update delays of n_p

samples and measurement delays of n_m samples. Since the block R_i causes a unit delay, the total delay for one update is $n_{total} = 1 + n_p + n_m$. The environment block represents the radio channel $G_i(t)$ [dB], interference $I_i(t)$ [dB] and the fraction $\delta_i(t)$ [dB] of desired signal power.

An outer power loop adjusts the required SIR $\gamma_i^t(t)$, to assure that QoS is unbroken. Outer power loop control can be based on block error rate BLER, or bit error rate BER. Open loop power control mechanism is not depicted on the Fig. 1. This is used only to provide a coarse initial power setting of MS at the beginning of a connection (the fast fading is essentially uncorrelated between uplink and downlink, due to the large frequency separation in FDD mode).

Simulations presented in this article are mainly focused on uplink communication between MS and BS, hence following section deals with uplink power control. MS sends control and data information (control and data channel). The BS actually estimates SIR of the control information and uses it for power control. Control channel using the power $p_{MSi}^C(t)$ and the remaining power $p_{MSi}^D(t) = \beta_i p_{MSi}^C(t)$ is used by data channel. Value β_i depends on the data rate and is signaled to the MS during call setup procedure, and can be change when network signals to MS to change the data rate. This means, that the power control is not affected by data rate changes or by discontinuous transmission, where the mobile not fully utilizes the assigned data rate all the time. The output power level of MS:

$$p_{MSi}(t) = (1 + \beta_i) p_{MSi}^C(t) \tag{10}$$

The pilot signal together with the control information is sent for SIR estimation and result is transmitted back as fast as possible, so the power can be updated with minimal delay. The estimation accuracy is strongly dependent on number of bits considered in the estimation and therefore on the delay [1].

The power level (Fig. 1) is increased or decreased depending on the received (one or more) TPC commands. The situation in uplink is slightly complicated by soft handover possibility. In soft handover the MS is connected to the several BSs simultaneously and MS receives power control commands from every BS; therefore power level of MS is increased only if all TPCs are equal to +1, otherwise the power level is decreased. For the best performance, the MS should control its power with respect to connection with that BS which has the most favorable propagation conditions [1].

4. UPLINK SIMULATIONS

The simulation results for uplink are depicted on the fig. 2. The basis of simulations was the model of WCDMA network [11,14] with 9 cells and several mobile subscribers in the each cell (two groups of MSs are considered in the cell: one “traced” MS and several interference MSs) [6]. The power control algorithm was adopted from [4] and fixed power control steps were used. The main goal of simulations was to present impact of TPC delay to achieved modified data rate R_{mod} (modified data rate is the average data rate with regard to satisfied user [5]) and probability of outage P_{out_su} (with regard to satisfied user [5]). Two average subscriber speeds (5km/h and 75km/h) are compared and Pedestrian test environment was used for both simulations: small cells size, non-line of sight and pedestrian radio channel type B [7][1]. The modified data rate on Fig. 2 is the average L1 data rate of all 9 traced MSs, which were using QPSK modulation schema and spreading factor SF = 8 [10].

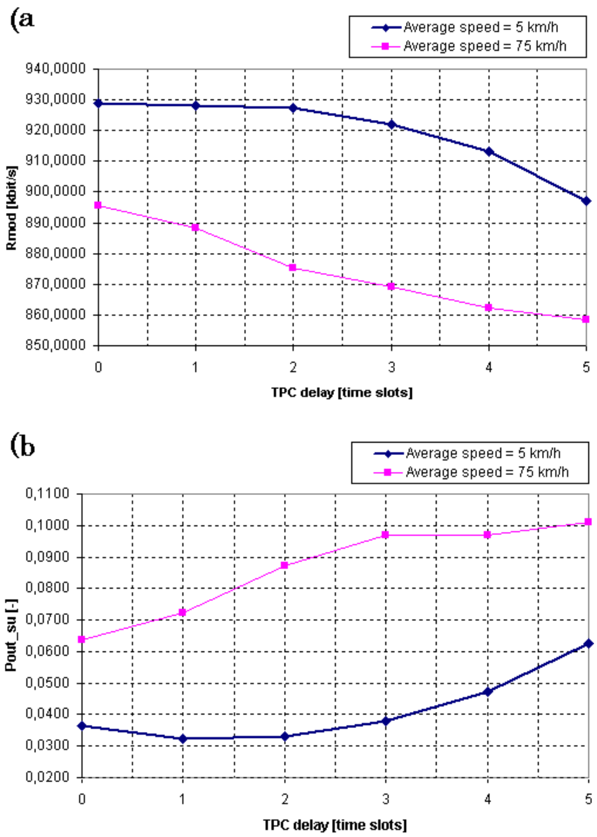

Fig. 2 Simulation results – Pedestrian environment
a) R_{mod} b) P_{out_su}

TPC delay equals to zero represents the ideal power control feedback. MS has the information about uplink channel state immediately and according to this information the output power level

[1] model of radio channel includes three basic parts: path loss - Low Range Outdoor model, shadow fading and short-term fading [7]

can be changed very fast. Simulated WCDMA system supports transmission of power control command bit $s_i(t)$ with frequency of 1500Hz (Fig. 1), as well as 3GPP UMTS. We can see on the Fig. 2 that R_{mod} decreases and P_{out_su} increases with TPC delay ingat MS average speed 5km/h. The difference between R_{mod} at TPC delay 0 and at TPC delay 2 is very small. Greater difference appears at TPC delay equal to 3. The channel fading is more unfavorable at higher MS speed. This caused lower R_{mod} and higher P_{out_su} at speed equals to 75km/h. However we can observe on Fig. 2a, that difference between ideal feedback and TPC command delayed 2 time slots is much bigger than in 5km/h case. The same behavior can be observed on Fig. 2b. In these simulations, results are represented only by constant TPC delay, but it's changing during MS movement in (between) cells. Also, we didn't take into account power control errors.

5. CONCLUSION

Various techniques of power control were described in the literature [15], but the main objective is always the same: to achieve required QoS. There are still many problems to be solved, or improved. Quality of estimation can be increased by prediction of channel state. Soft handover represents a central part in third generation systems and power control algorithms have to consider all aspects and situations [1]. In this article we have simulated the influence of power control delay in WCDMA mobile communication networks. It is obvious, that the influence of power control delay to some important performance parameters depends on mobile channel environment.

REFERENCES

[1] Gunnarsson, F., Gustafson, F.: *Control Theory Aspects of Power Control in UMTS.* Linköpings universitet in Linköping and Ericsson Research in Linköping, Sweden, 2001.

[2] Gunnarsson, F., Gustafson, F.: *Power Control in Wireless Communications Networks – from a Control Theory Perspective.*. Linköpings universitet in Linköping and Ericsson Research in Linköping, Sweden, 2001.

[3] 3GPP TS 25.214 V5.11.0 (2005-06): *Physical layer procedures (FDD).*

[4] Castro, P. J.: *The UMTS Network and Radio Access Technology - Air interface Techniques for Mobile Systems.* Willey, USA, 2001.

[5] Pšenák, V., Wieser, V.: *SIR-based hybrid link adaptation algorithms in mobile communications networks.* 28th International Conference Telecommunications and Signal Processing TSP-2005. Brno University of Technology, pp 78-81, ISBN 80-214-2972-0

[6] Laiho J., Wacker, A., Novosad, T.: *Radio Network Planning and Optimization for UMTS.* Wiley, USA, 2002.

[7] ETSI TR 101 112 V3.2.0. (1998-04): "*Selection procedures for the choice of radio transmission technologies of the UTMS*".

[8] Holma, H., Toskala, A.: *WCDMA for UMTS. Radio Access for Third Generation Mobile communications.* Wiley, USA, October 2000, ISBN 0-471-72051-8.

[9] Rappaport, T.S.: *Wireless Communications. Principles and Practice.* Prentice Hall, New Jersey, USA, 1996.

[10] 3GPP TS 25.213 V6.2.0 (2005-03): *Spreading and modulation (FDD).*

[11] Cátedra, F.M., Pérez-Arriaga, J.: *Cell Planning for Wireless Communications.* Artech House Publishers, Boston, USA, 1999.

[12] Hrdina, Z., Vejražka, F.: *Digitální rádiová komunikace*, Vydavatelství ČVUT, 1995.

[13] 3GPP TS 25.212 V6.4.0 (2005-03): *Multiplexing and channel coding (FDD).*

[14] Wieser,V., Pšenák, V.: *WCDMA Mobile Radio Network Simulator with Hybrid Link Adaptation,* Advances No.3, Vol.4/2005, ISSN 1336-1376

[15] Doboš, Ľ. - Dúha, J. - Marchevský, S. - Wieser, V.: Mobilné rádiové siete. Odborná knižná publikácia, Vydavateľstvo Žilinskej univerzity EDIS, 2002, ISBN 80-7100-036-9